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COMPARISON OF VARIOUS TYPES OF ROOFTOP GRID CONNECTED SOLAR PLANTS: A CASE STUDY

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ABSTRACT

The growing electrical energy demand in developing countries like India has triggered the scientists and engineers to think of new and innovative methods in the field of renewable energy sources especially solar energy. Grid connected PV systems have become the best alternative to bulk electrical power consumers like industries and other institutions. In this paper 280kWp Photovoltaic grid connected power plant commissioned at CVR College of Engineering is taken for research study. This plant uses three mechanisms to trap the solar energy from the sun to produce electrical energy from the solar array. Out of three mechanisms, Single axis Polar tracking, Single axis tracking power plants produce more amount of electrical energy compared to seasonal tilt power plant. The energy outputs of Single Axis Polar tracking power plant and Single axis tracking power plant are compared from May '15 to September '16. After observing the energy outputs from each power plant, the entire 12 months of time in a year is divided into two time frames viz. from October to March and other from April to September. In one time frame Single Axis Polar tracking power plant is giving better performance whereas in other time frame Single axis tracking power plant is giving better output.

KEYWORDS: Grid Connected Solar Power Plant, Polar Tracking, Single Axis Tracking, Solar Radiation & Seasonal Tilt

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INTRODUCTION

Increasing Electrical Energy demand and high cost fossil fuels, global warming and environmental issues are key issues to use of renewable energy sources. There are various types of naturally available sources of energy which can be replenished over a period of time. Solar energy, Wind energy, Ocean Energy, Geo-thermal energy and Biomass energy are few to mention. Today's daily Electrical energy needs, cost of fossil fuels and effect of greenhouse gases on environment forces the industrial and other institutions to seek for new methodologies to generate their own electrical power through renewable energy.

Most of the parts in India receive abundant Solar radiation with more than 300 average sunny days in an year. The following features of Solar energy make it the most reliable renewable source of energy when compared to other renewable sources:

- Available across the entire country– un like other renewable sources, which have geographical limitations.
- Decentralized/off-grid applications–addressing rural electrification issues.

Case Study

- Modularity and scalability.

In India, Solar energy became the best alternative renewable energy to fulfill the energy requirements of majority of the people living in both urban and rural areas for variety of applications. There are two ways by which we can convert solar energy into electrical energy.

- **Solar Thermal**

The solar collectors collect and convert the sunlight to heat. This heat will be transferred to the fluid to increase the temperature of the working fluid. This heated fluid is then used to generate steam that drives a prime mover to, produce electrical energy.

- **Solar Photovoltaic**

Another way to generate electricity from solar energy is to use photovoltaic cells, which are made up of silicon that converts the solar energy falling on them directly into electrical energy. This is a direct energy conversion which involves photo-electric effect. Large scale applications of photovoltaic for power generation, either on the rooftops of houses or in large fields connected to grid provide clean, safe and strategically sound alternatives for production of electrical power generation.

PV is progressively becoming more attractive, than other renewable sources of power, as it s cost declining and simplifying the complexities involved using modern technologies and remedies.

Solar PV has the potential to transform the lives of many people, who rely on highly subsidized kerosene oil and other fossil fuels, primarily to light up their homes. Grid connected solar power plant is the one of the solution to reduce the demand supply gap in the power sector.

TYPES OF PHOTO-VOLTAIC SYSTEMS

On the basis working operation PV systems operate in four basic forms [4].

- Grid Connected PV Systems
- Standalone Systems
- Hybrid System
- Grid Tied with Battery Backup PV System

Out of all above mentioned Solar PV systems, the grid connected roof top solar PV system has some more benefits to full fill the large scale energy demand of industries or institutions.

The following are the benefits of grid connected roof top SPV systems:

Reduction in electrical energy consumption from the grid.

Reduction in diesel consumption wherever DG backup is provided.

Feeding excess power to the grid.

For above mentioned reasons, grid connected solar PV system is preferred when grid is available and diesel generator as backup [5,6].

Grid Connected PV Systems

The "Figure 1," shows the block diagram of Grid connected PV plant with net metering. These systems are connected to a broader electricity network. The PV system is connected to the utility grid using a high quality inverter. This inverter converts DC power from the solar array into AC power and is synchronized to the grid with the help of suitable transformer. During the day, the solar electricity generated by the system is either used immediately or sold off to electricity supply companies. In the evening, when the system is unable to supply immediate power, electricity can be imported from the network.

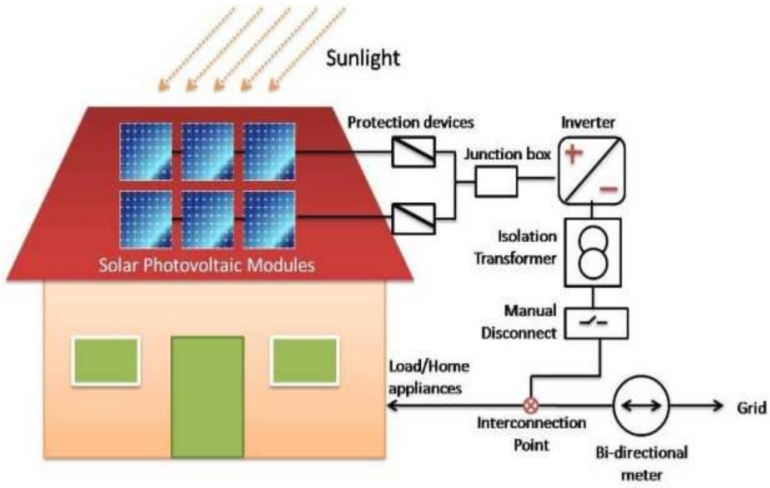

Figure 1: Block Diagram of Grid Connected PV Plant with Net Metering

Site Details

Grid connected Solar Power Plant under this research study is located on roof top of CVR College of Engineering. This college is located in Vastunagar, Mangalpalli village, Ibrahimpatnam mandal located in Telangana State in India.

Project Location	**Climate Data Location**
Location: Hyderabad	Location: Hyderabad
Latitude: 17.20 ˚N	Latitude: 17.45 ˚N
Longitude: 78.60 ˚E	Longitude: 78.47 ˚E
Elevation: 545.00 m	Elevation: 545.00 m

The solar radiation data of project location is not available exactly. So the solar radiation data and other climate conditions at project location are assumed to be the same that is available at the nearest climate data location given by NASA [7]. Climate data of the location as per information provided by NASA are used for energy estimation using PVSYS software.

Plant Description

The capacity of Grid connected solar power plant located on Roof top of CVR College of engineering under the study is 280kW$_p$. Table II shows the various details of the sub-plants and their ratings etc. in the campus.

The Electrical Energy output of the Solar PV Power Plant is directly proportional to amount of Solar radiation that solar array will receive at any point of time. More the amount of solar energy received by the solar array, more the electrical energy output. vice-versa.

There are generally two methods to collect the energy from sun. One is, by placing the modules facing the north with some tilt with respect to horizontal roof on which panels are mounted. Figure 2 clearly explains the diagrammatic representation of the tilt of solar module. In this method for every month we need to adjust the tilt of solar modules. This is called seasonal tilting. but changing the position of solar panels every month is very laborious, we restrict the change the tilt of modules for every season.

The other method is track the position of sun such that solar panels collect maximum energy throughout the day. In these methods panels are oriented in East-West direction. The moment sun rises in the East, solar panels automatically face east direction. It will be horizontal when LST is 12:00 noon and will face the West in the evening. This method of tracking the sun is called Single-Axis tracking. Because it will track the sun path only in East-West direction.

Tracking method has definite advantage over seasonal tilting as it produces more amount if electrical energy. However, initial cost to set up tracking mechanism for solar panels is expensive.

The small draw back in single axis tracking is solar radiation still not maximum as it follows the only east-west direction. The best method is to track the sun in North-South direction. This method is called Two-axis tracking. To implement two-axis tracking for solar plant on roof top it needs large rooftop area and also control mechanism for solar array to face the sun exactly 90^0 is quite complex and expensive.

In two-axis tracking the change in north-south position angle of solar array is not big throughout the year. Hence to take the advantage of the two axis tracking with cost of single axis tracking an innovative method named single axis polar tracking method is implemented on 40kWp solar plant commissioned on the Main block of college. This single-axis polar tracking power plant output giving us scope to go for further research over a period of time.

So the new classification of Solar power plants based on the way how the solar array receives the solar energy from the sun can be categorized into three types

- Seasonal Tilt/Manual tilt
- Single- Axis Tracking
- Single- Axis Polar Tracking

Out of 280kWp of installed capacity, 120kWp on rooftop of EEE Block and 20kWp on rooftop of Library block use the Seasonal tilt mechanism.40 kWp on Main block and 60kWp on CSE block uses single axis tracking mechanism and another 40kWp on main block uses single axis polar tracking mechanism to extract the Solar energy from the sun. Overall, 140 kWp solar plant uses seasonal tilt mechanism and remaining 100 kWp solar plant uses single axis tracking mechanism and 40kWp uses Single axis polar tracking mechanism for electrical power generation [8]. Table 1 shows the overall plant capacities and type of tilting etc.

Table 1: Details of Name of Sub PLANTS, their Capacities and Date of Commencement of Plant

S. No	Location of Plant	Installed Power in kW_p	Method of Solar Energy Collectionfrom the Sun	Date Plant Synchronized to Grid
1	EEE Block	120	Seasonal Tilt	03-03-2014
2	Main Block	40	Single axis Tracking	18-01-2015
3	Library	20	Seasonal Tilt	23-02-2015
4	Main Block	40	Single axis Polar Tracking	11-03-2015
5	CSE Block	60	Single axis Tracking	22-10-2015
Total Installed Capacity		**280**	----	----

- **Seasonal Tilt/Manual Tilt**

In seasonal tilt mechanism the panels will face due south with some tilt with respect to the horizontal. Stationary mounts hold these solar PV panels in a fixed position. This is very simple mechanism, doesn't involve any moving structures, rugged and solid support to modules. the main disadvantage of the system is For every three months we have to manually adjust the tilt angle of the solar array.

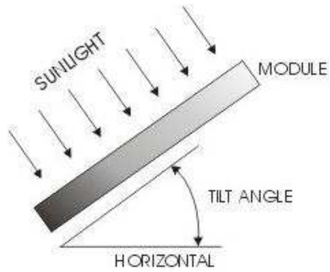

Figure 2: Diagram Showing the Tilt of Solar Module with Respect to Ground

- **Single- Axis Tracking**

In this mechanism the panels face East- West with the axis of rotation points North- South. The axis of rotation for single axis tracker is horizontal with respect to the ground. These trackers are driven by either by stepper motors or synchronous motor with gear mechanism. The simple geometry means that keeping all of the axes of rotation parallel to one another is all that is required for appropriately positioning the trackers with respect to one another. As a module tracks, it sweeps a cylinder that is rotationally symmetric around the axis of rotation. In single axis horizontal trackers, a long horizontal tube is supported on bearings mounted upon pylons or frames. The axis of the tube is on a north–south line. Panels are mounted upon the tube, and the tube will rotate on its axis to track the apparent motion of the sun throughout the day.

- **Single- Axis Polar Tracking**

In Single-Axis tracking, the modules are mounted flat at 0^0 degrees with respect to the horizontal. Whereas in Single Axis Polar Tracking the modules are installed at a certain tilt (10 degrees) with respect to horizontal axis. It works on same principle as Single- Axis Tracking, keeping the axis of tube horizontal in north–south line and rotates the solar modules from the east to the west throughout the day. These trackers are usually suitable in high latitude locations.

The main advantage of Solar trackers is they can generate more electricity than seasonal tilt modules due to an increased direct/beam solar radiation incidence on panels. Other disadvantage is that they will implement little bit complex technology and moving parts leading to more cost compared to stationary seasonal tilt mechanism.

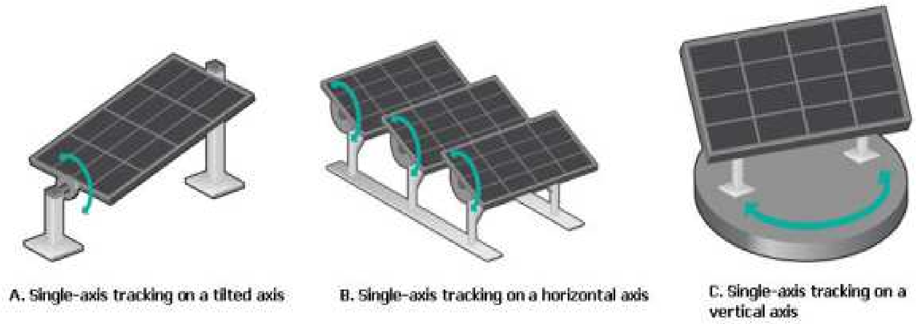

Figure 3: Schematic of Single Axis Tracking, Polar Tracking and Vertical Single Axis Tracking

Components of Grid Connected Solar Plant include

- Solar Panels/ Solar Modules/ Solar Array
- String inverter
- DC Cables
- AC Cables
- Junction Boxes
- Net meter (bi-directional Meter)

The "Figure 4," shows the schematic diagram of grid connected plant with net metering facility. In short, Solar panels/ Modules/Array will collect the energy from the sun in the form of solar radiation. this solar radiation is converted into DC electrical energy by solar Array. This DC Electrical energy is given as input to grid interactive String inverters with the help of DC Cables. These string inverters converts DC electrical Energy into AC electrical energy. The output AC electrical energy of inverter will be sent to local junction box with the help of AC Cables. From the junction box depending upon local load requirement the AC power will be either pumped to electrical grid or utilized for local energy requirements. There will be a bi- directional energy meter is installed at incoming transformer from the external grid [10]. Generated Solar Electric Power is synchronized at 11kV bus. This bi directional energy meter increments the energy units when ever local load requirement is more than AC electrical energy output of solar plant and vice-versa.

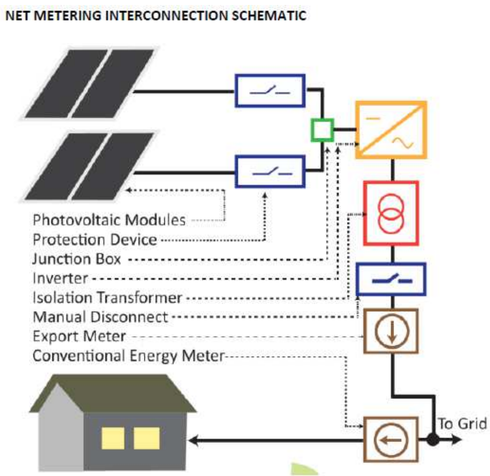

Figure 4: Schematic of Grid Connected Solar Power Plant under Net Metering Scheme

As we discussed in the chapter-II, this grid connected solar plant has three different configurations depending upon the way solar panels receives the energy from the sun.

Figure 5: 20kWp- Library Seasonal Tilt Power Plant

The above "Figure 5," shows the exact on site photograph of 20-kWp seasonal tilt power plant commissioned on Library block of CVR College of Engineering. The below "Figure 6," shows the exact on site photograph of 40-kWp Single axis tracking power plant commissioned on Main block of CVR College of Engineering and also shows the position of solar array at 9:30 A. M. towards the east, 12:30 P. M exactly horizontal and at 3:00 P. M Facing the West.

Figure 6: Single Axis Tracking-Position of Panels at 9:30 A. M, 12:30 P. M & 3:00 P. M Respectively

As mentioned earlier Single axis tracking plant always follows the position of the sun in the sky throughout the day to collect the maximum energy from the sun.

In Single axis tracking power plant, the axis of rotation of panels make an angle Zero degrees (0^0) with respect to horizontal. In this scheme as the North-South Position of the sun is restricted to zero degrees, panels may not face the sun rays near to perpendicular position (90^0) because the sun path is not same throughout the year. So as an experimental idea, to face the Solar Array near to 90^0 towards the sun for the most of the time in a year, horizontal axis of single axis tracking plant is made a tilt of 10^0 with respect to horizontal. This plant is named as Single Axis tracking power plant. The "Figure 7," shows the 3-D view of idea of Single axis tracking power plant & onsite photograph of Polar tracking power plant.

Solar Panels and string inverters are the heart of grid connected solar power plant. Multi crystalline Solar panels are used in the solar array. Each Solar panel has maximum output power of 250 Watt at 1000 W/Sq.m Solar radiation. Panels are manufactured by Kohima Energy Private Limited. Model Number of Solar panel is KE-60-M250 which has 25 years' of manufacturer guarantee.

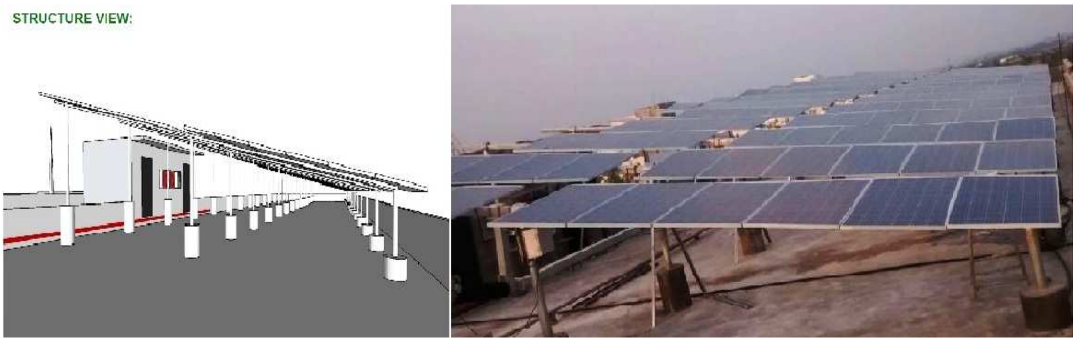

Figure 7: 3-D view of Single Axis Polar Tracking& Onsite Photograph of Polar Tracking Power Plant

The inverters used in this power plant are 20-kW Refusol grid interactive string inverter. Model number is REFUsol 008K-020K. This is a three phase sine wave inverter as per IP 65 standards with maximum efficiency of 98.2%. The “Figure 8,” shows the REFUsol 008K-020K string inverter & Kohima Solar Module of 250kW$_p$.

Figure 8: 20kW Refusol String Inverter & KE-60-M250 Kohima Solar Module of 250kW$_p$

RESULTS AND DISCUSSIONS

The online monitoring of data related to energy output of each and every string inverter is by web interface of Refusal string inverter [11]. With this interface, the energy outputs of 20kW string inverter from each seasonal tilt Power Plant, Single axis tracking Power plant and Polar tracking power plant are extracted over the period i.e from May '15 to September'16.

The energy outputs of each sub plant over monitored period are tabulated in Table 2. The “Figure 9” shows the graphical representation of energy outputs of 20kW string inverters from each seasonal tilt Power Plant, Single axis tracking Power plant and Polar tracking power plant in area chart pattern. By analyzing the data of Table III, we can conclude that during the period from April to September the energy generated by Single axis tracking power plant is more than other two plants. Whereas from October to March it is evident that Single Axis Polar tracking power plant is more than others.

As performance of both plants is varying between the two time frames i.e One time frame is taken from April to September and another time frame from October to March. For better study on the performance of the both plants, one random date is taken from each time frame. 22nd May 2016 is taken for one-time frame and 14th October 2016 is taken for other time frame.

Table 2: Month Wise Electrical Energy Outputs of Seasonal Tilt, Tracking and Polar Tracking Power Plants

Month- Year	Seasonal Tilt Mechanism	Single Axis Polar Tracking	Single Axis Tracking
May'15	2855.30	3230.80	3390.90
June'15	2133.30	2242.50	2474.20
July'15	2662.90	2967.80	3101.30
August'15	2367.70	2564.70	2585.10
September'15	2248.60	2545.80	2529.50
October'15	2148.60	3010.60	2859.20
November'15	2328.70	2559.80	2395.90
December'15	2567.00	2817.70	2621.10
January'16	2606.70	2679.70	2575.30
February'16	2744.10	3036.40	2858.60
March'16	2791.40	3224.70	3155.20
April'16	2720.00	3166.10	3188.40
May'16	2788.50	3113.60	3246.70
June'16	2207.40	2302.70	2479.40
July'16	2063.50	2083.00	2213.10
August'16	2283.10	2505.10	2586.60
September'16	1720.40	1883.20	1894.00

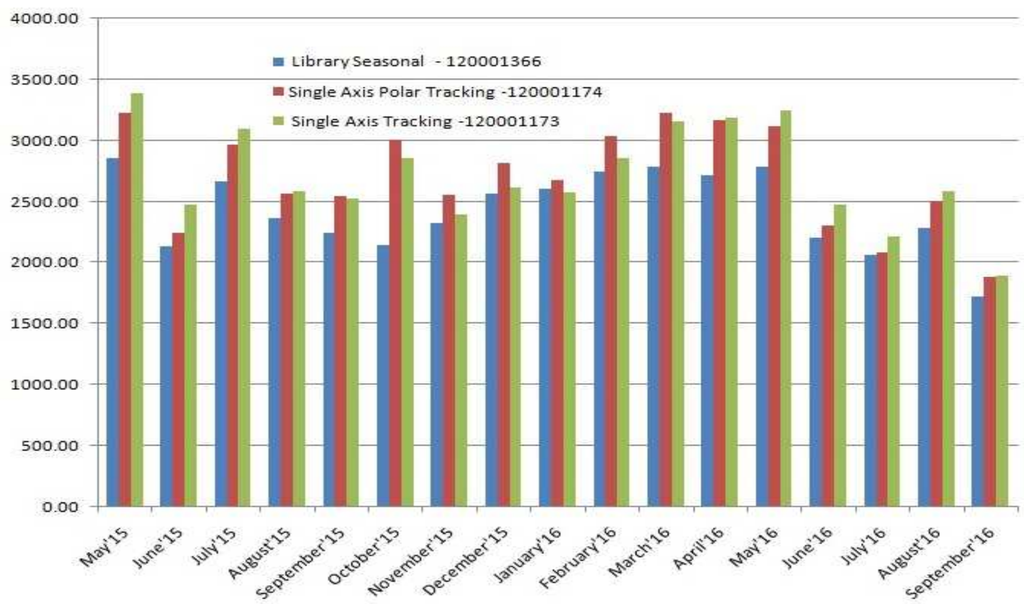

Figure 9: Energy Outputs of Seasonal Tilt Plant, Single Axis Tracking Power Plant, Single Axis Polar Tracking Power Plant Over a Monitored Period

The "Figure 10," shows the energy outputs of each 20kw string inverter which are connected to Single axis polar plant, Single axis tracking plant and Seasonal tilt power plants. From the figure one can conclude that Single axis polar plant is best among three power plants [12]. Similarly, the "Figure 11," shows the energy outputs of each 20kw string inverter which are connected to Single axis tracking plant, Single axis polar plant and Seasonal tilt power plants. It is evident from charts that that Single axis tracking plant is best among three power plants.

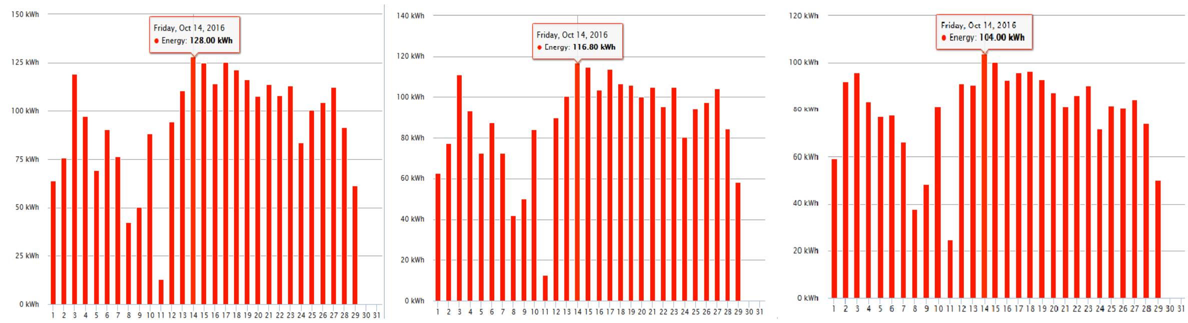

Figure 10: Energy Generated by Single Axis Polar Tracking-20kW String Inverter Output, Single Axis Tracking-20kW String Inverter Output & Seasonal tilt -20kW String Inverter Output on 14th October '16

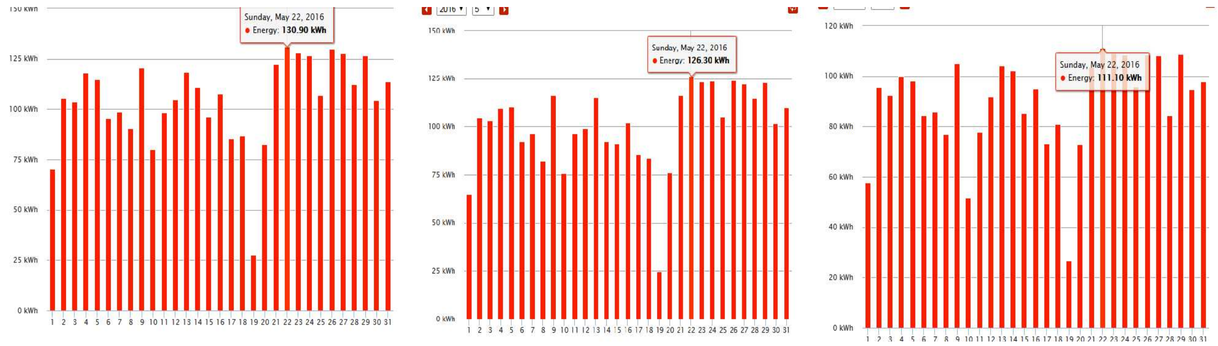

Figure 11: Energy generated by Single Axis tracking-20kW String Inverter Output, Single Axis Polar Tracking-20kW String Inverter output & Seasonal Tilt -20kW String Inverter Output on 22nd May '16

After comparing the outputs, we can conclude that from October to March Polar tracking power plant gives more output. Whereas from April to September Single Axis tracking gives more output [12].

CONCLUSIONS AND FUTURE SCOPE

In this research article, a 280kWp Grid Connected Photo-Voltaic Power Plant commissioned on rooftop of CVR College of Engineering is taken for the study. This plant uses three mechanisms to trap the solar energy from the sun to produce electrical energy from the solar array. The output electrical energies of these three mechanisms are studied and analyzed for a period of 17 months.

The twelve months' time in a year is divided into two time frames One is from October to March and other from April to September for research analysis. During first time frame Single axis tracking power plant is giving better performance whereas in the second time frame Single Axis Polar tracking power plant is giving better output. Further research has to be done on these results for better analysis and exact reasons to investigate performance of the plant in these two different time frames.

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REFERENCES

1. *R. E. P. N. for the 21st Century, "Renewables 2012 global status report," tech. rep.,*
2. *India Solar Resource Maps (2010): http://www.mnre.gov.in/centers/about-sec- 2/solar-resources/, Ministry of New and Renewable Energy Govt. of India*
3. *Sukhatme and Nayak, Solar Energy: Principles of Thermal Collection and Storage, Tata McGraw. Hill, 2008*
4. *J. A. VENTRE et al., Photovoltaic systems engineering. CRC press, 2004.*
5. *L. M. Ayompe, A. Duffya, S. J. McCormack, M. Conlon, "Measured performance of a 1.72 kW rooftop grid connected photovoltaic system in Ireland," Volume 52, Issue 2, February 2011, Page 816-825.*
6. *M. Sidrach-de-Cardona, Ll. Mora Lopez, "Performance analysis of a grid-connected photovoltaic system," Energy 24 (1999); 93–102.*
7. *Solar Radiant Energy over India. (2009) ed. Ajit P. Tyagi, India Metrological Department, Ministry of Earth Sciences, Govt. of India*
8. *P. B. Miro Zeman, "Photovoltaic systems reader." University Lecture, 2013.*
9. *IEC, "Photovoltaic system performance monitoring- guidelines for measurement, data exchange and analysis," IEC standard 61724, Geneva, Switzerland; 1998*
10. *M. Zeman, "Photovoltaic basics syllabus." University Lecture, 2011.*
11. *Khatib, T., Sopian, K., Kazem, H. Actual performance and characteristic of a grid connected photovoltaic power system in the tropics: A short term evaluation. Energy Conversion and Management. 71(2013): 115–119.*
12. *Deepthi. S, Ponni. A, Ranjitha. R, R Dhanabal, "Comparison of Efficiencies of Single-Axis Tracking System and Dual-Axis Tracking System with Fixed Mount", International Journal of Engineering Science and Innovative Technology (IJESIT), Volume 2, Issue 2, March 2013.*